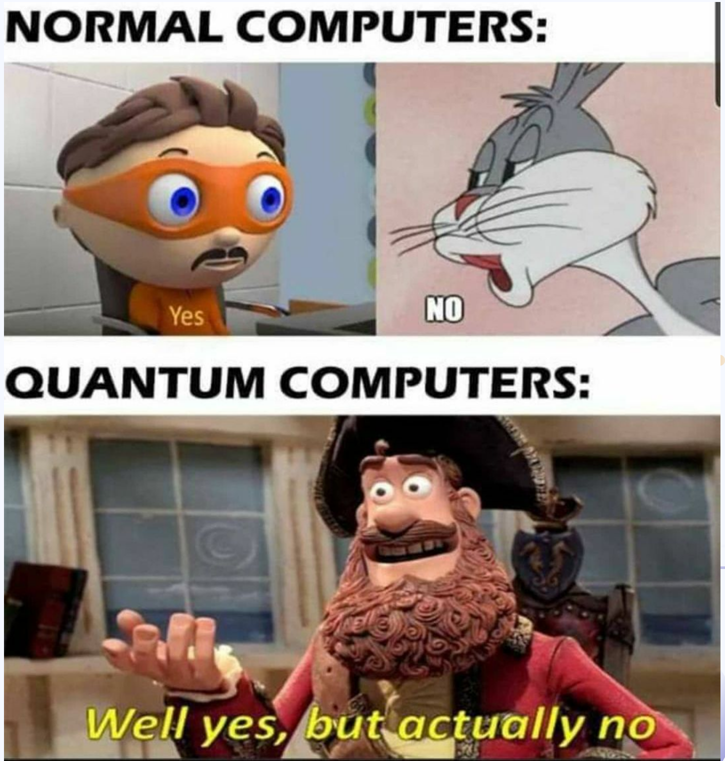
Unconventional computers



Conventional architecture summary

Use parallelism to improve performance

Balance tradeoffs (e.g. using hierarchies)

Be aware of application when designing HW and vice versa

Rely on physics/EE, up to a point

Don't forget about correctness, power, security, usability…

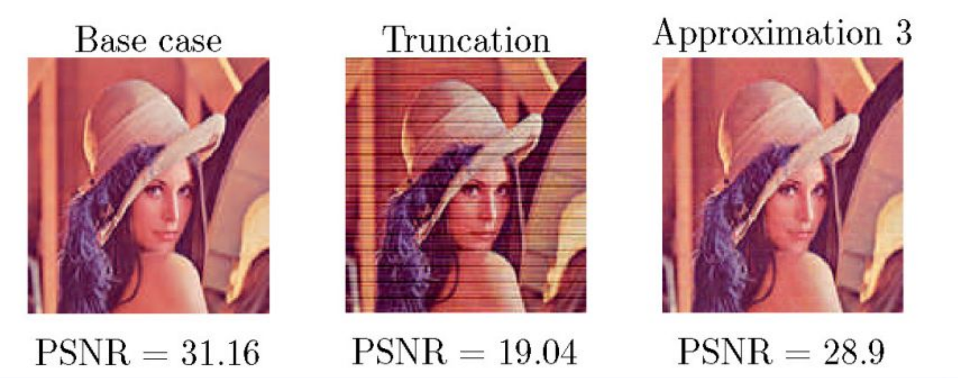
What if we relaxed some of our traditional views of computing?

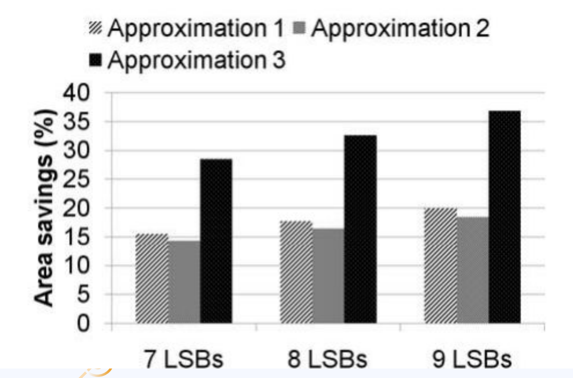
Approximate computing

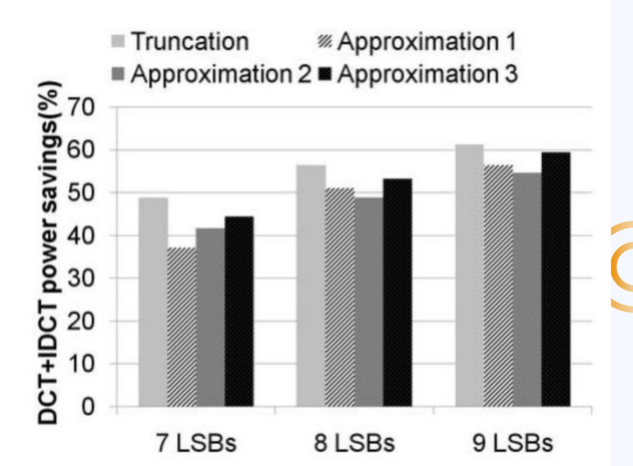
V. Gupta, D. Mohapatra, S. P. Park, A. Raghunathan and K. Roy, "IMPACT: IMPrecise adders for low-power approximate computing," IEEE/ACM International Symposium on Low Power Electronics and Design, Fukuoka, Japan, 2011, pp. 409-414, link

Reduce correctness expectations for gains in speed, energy

- Remove gates (e.g. carry bits) from arithmetic circuits
- Truncate data/remove precision
- Reduce memory reliability
- Skip loop iterations/end before convergence



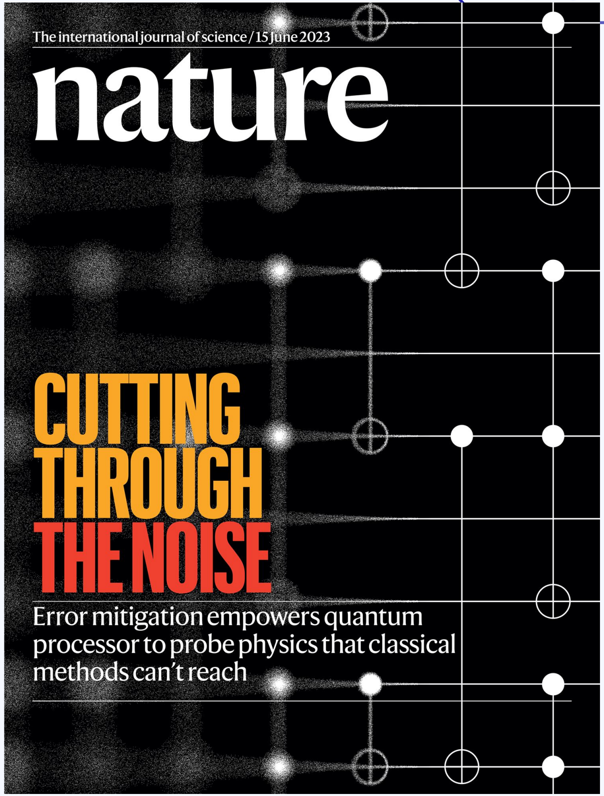




A new paper from IBM and UC Berkeley shows a path toward useful quantum computing

A useful application for 127-qubit quantum processors with error mitigation.

"With the confidence that our systems are beginning to provide utility beyond classical methods alone, we can begin transitioning our fleet of quantum computers into one consisting solely of processors with 127 qubits or more."



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Quantum effects used today

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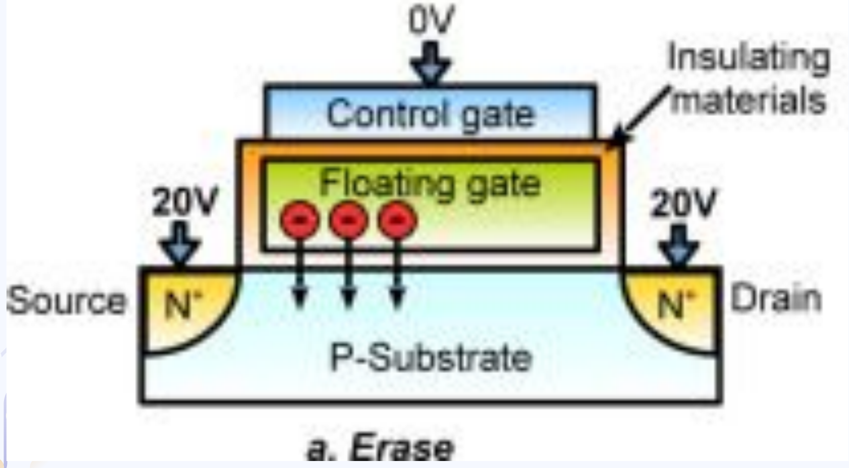

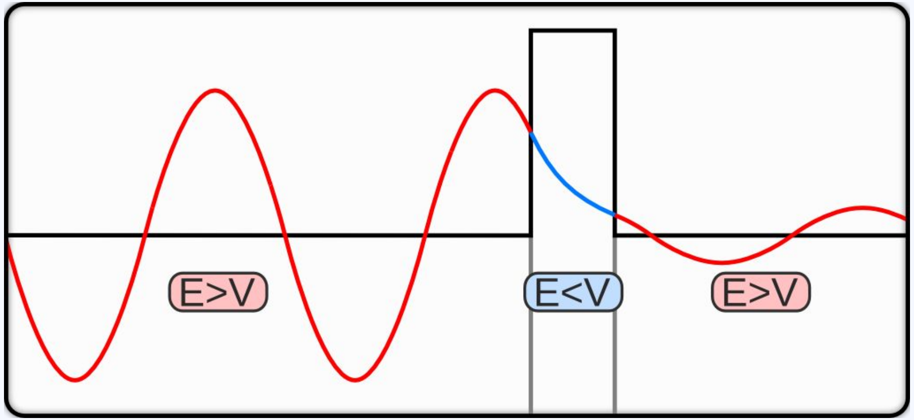

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Future of quantum applications

Cryptography

Physics simulations

AI/ML

Medicine

...

Note: Breakthroughs are being made, but current applications of quantum computers are very limited

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Probabilistic states

We can enumerate the states a system can be in

For coin: {Heads, Tails}, or {0, 1}

We can also assign a probability to an outcome based on an event

For coin: ½ probability for each of 0/1 on flip

Notation: write probabilities as a vector or as a superposition of *observed* states

Superposition just describes "probabilistic state" of system

Quantum state and qubits

In previous slide: sum of entries in probabilistic vector must be 1

Quantum state: Probabilistic vectors where the entries can have complex quantities

Sum of squared magnitudes of entries must be 1

qubit (quantum bit): quantum state where the classical states are 0, 1

When quantum state is measured, classical state is observed with probability (square of magnitude of corresponding state entry)

Quantum circuits

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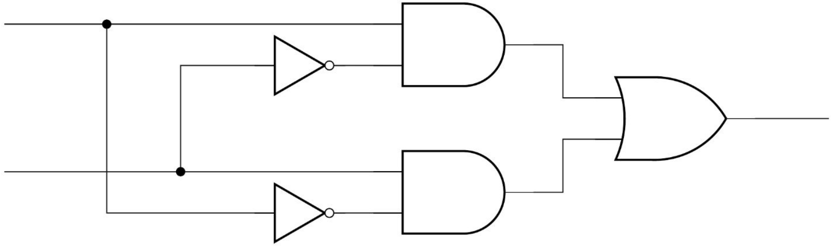
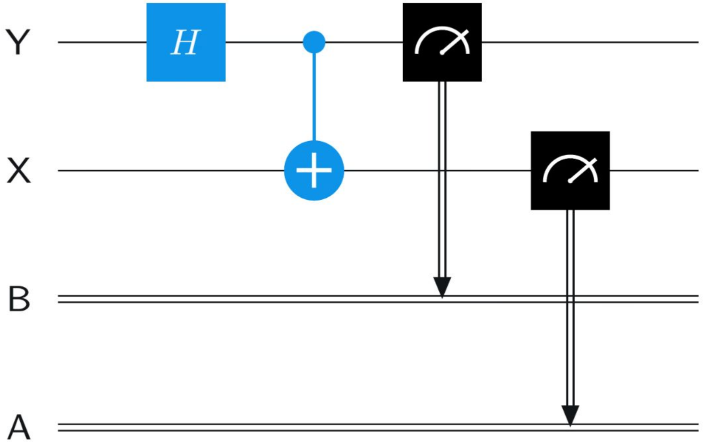
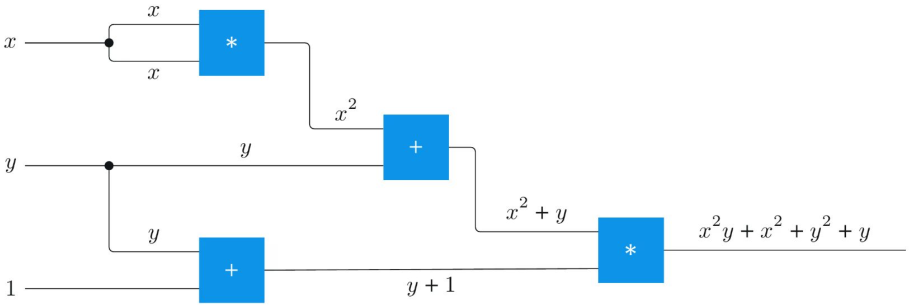
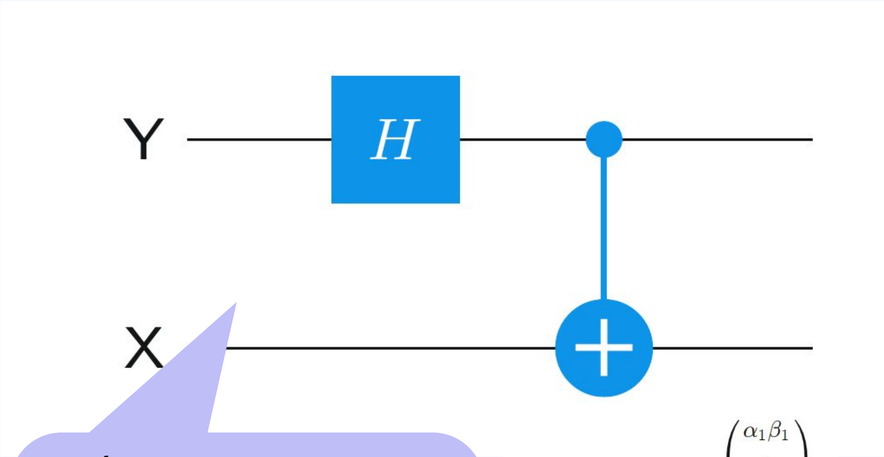




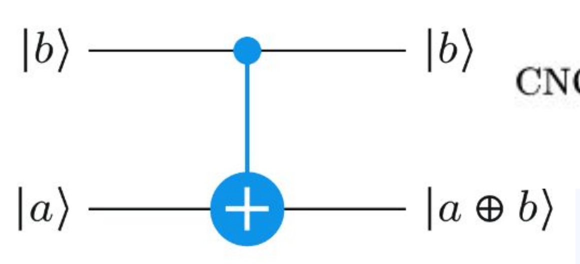


Hadamards and controlled-nots



$$H_1 = \frac{1}{\sqrt{2}}\begin{pmatrix} 1 & 1 \\ 1 & -1 \end{pmatrix}$$

Hadamard: turns basis state (0, 1) into superposition state and vice versa



$$\text{CNOT} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \end{bmatrix}.$$

Controlled-not: performs NOT operation on second qubit iff first qubit value is |1>

(Mathematically speaking) these are just matrix multiplications on individual qubits or systems of qubits

$$\begin{pmatrix} \alpha_1 \\ \vdots \\ \alpha_m \end{pmatrix} \otimes \begin{pmatrix} \beta_1 \\ \vdots \\ \beta_k \end{pmatrix} = \begin{pmatrix} \alpha_1\beta_1 \\ \vdots \\ \alpha_1\beta_k \\ \alpha_2\beta_1 \\ \vdots \\ \alpha_2\beta_k \\ \vdots \\ \alpha_m\beta_1 \\ \vdots \\ \alpha_m\beta_k \end{pmatrix}$$

Deutsch-Jozsa Algorithm

Designed to be exponentially faster on quantum vs classical computer

Given a black-box function $\{0,1\}^n \rightarrow \{0,1\}$ that is promised to either be constant (the same on all inputs) or balanced (0/1 for 50% of inputs), can we *query* the function to find out if it is balanced or constant?

Best-case and worst-case number of queries in classical algorithm?

constant

a	$f_1(a)$
0	0
1	0

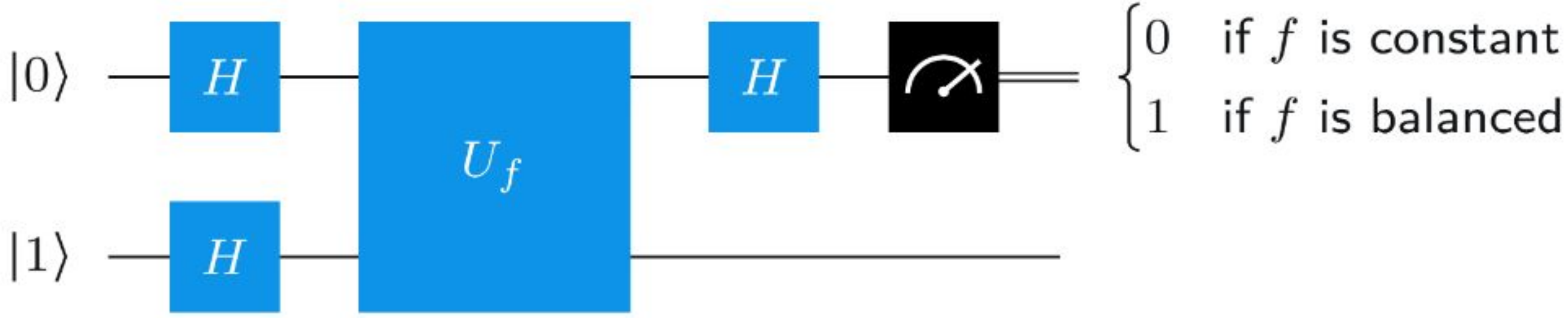
balanced

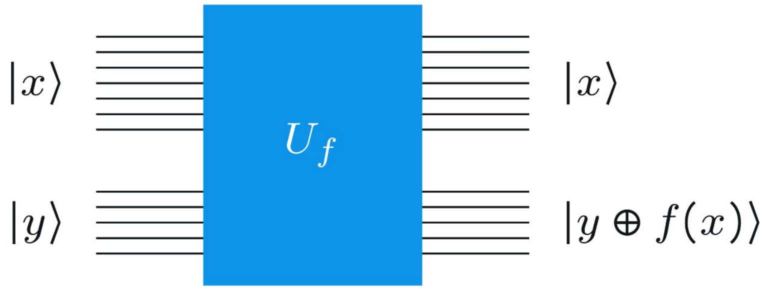
a	$f_2(a)$
0	0
1	1

a	$f_3(a)$
0	1
1	0

a	$f_4(a)$
0	1
1	1

Deutsch's algorithm (n=1)





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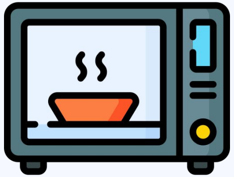
math derivation

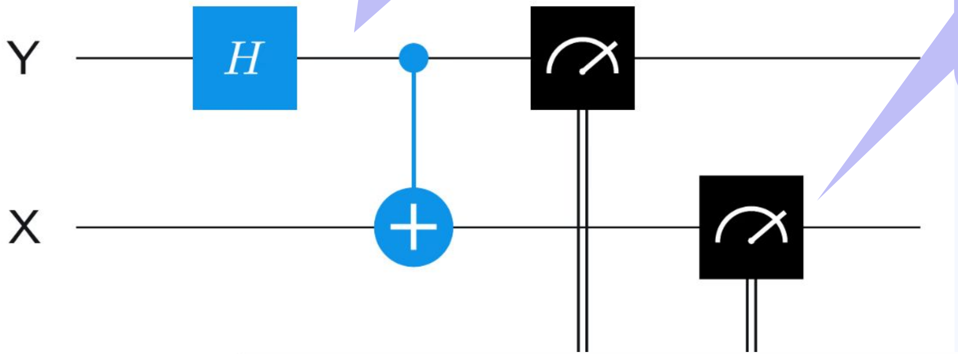
Challenges

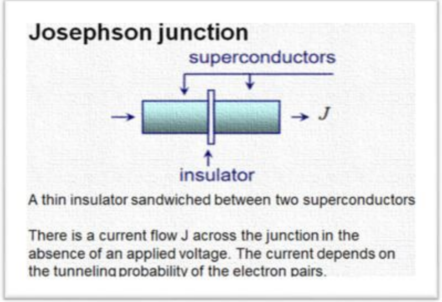
How to create and maintain a qubit?

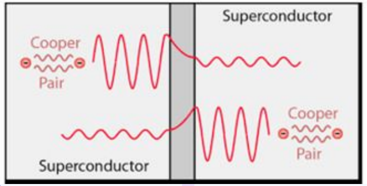
How to implement gates?



How to measure accurately?







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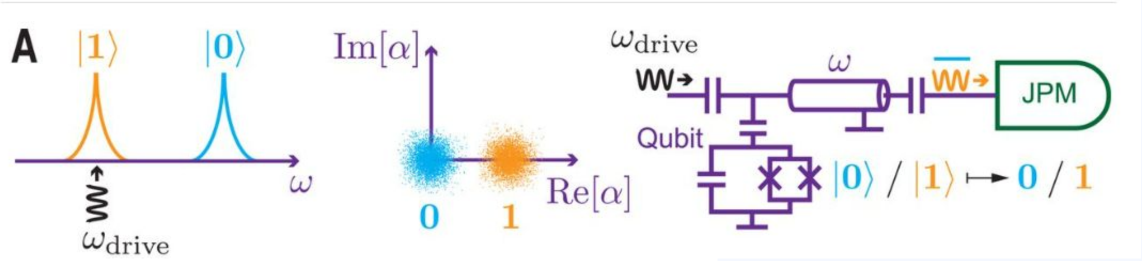

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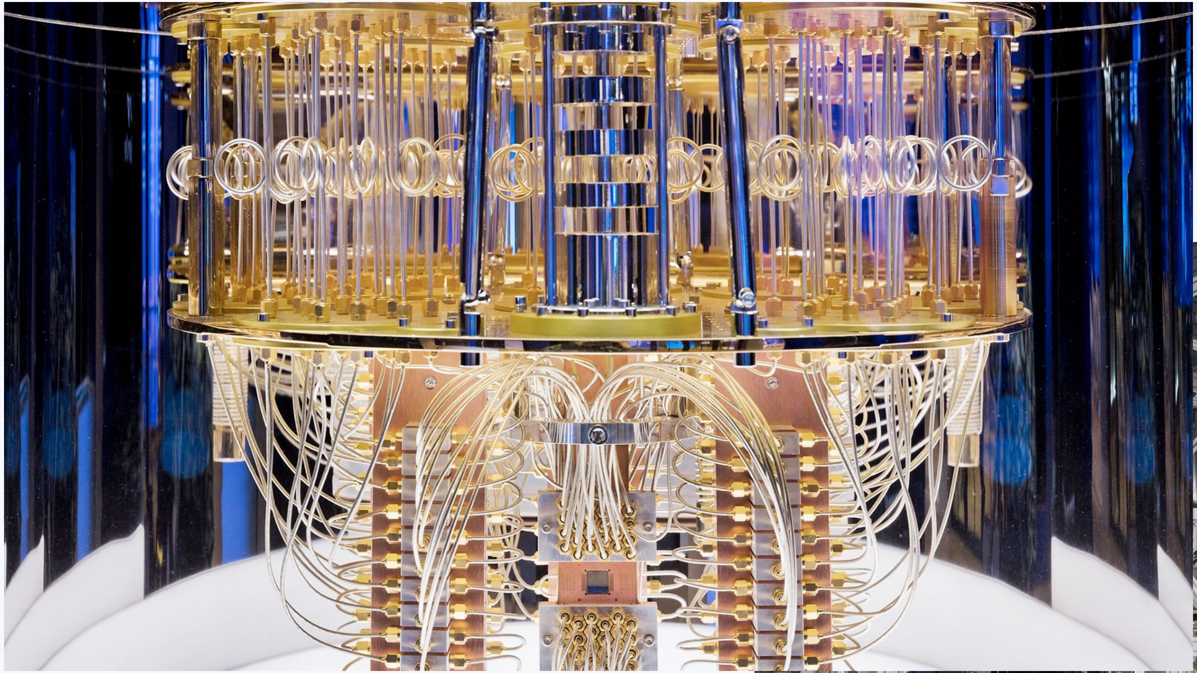

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this is not the computer… it's the fridge

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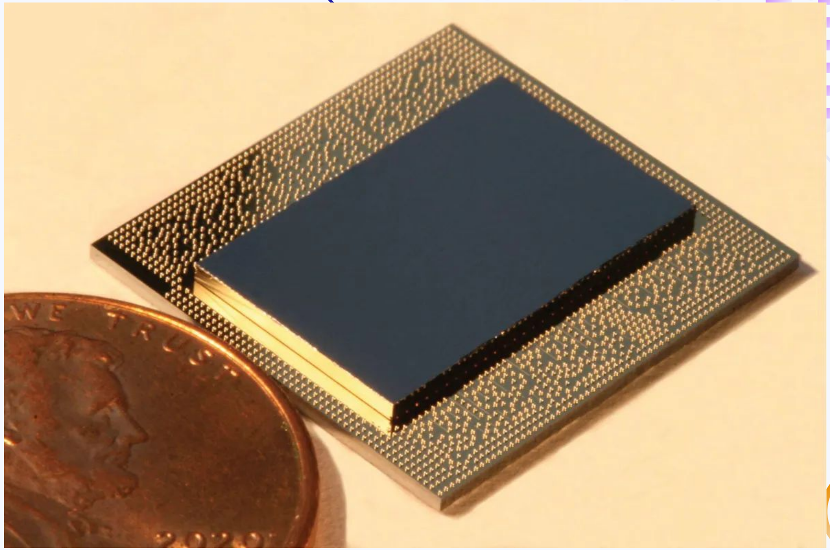

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Challenges for qubit stability:

- Keep them small
- Keep them cold

Reliability

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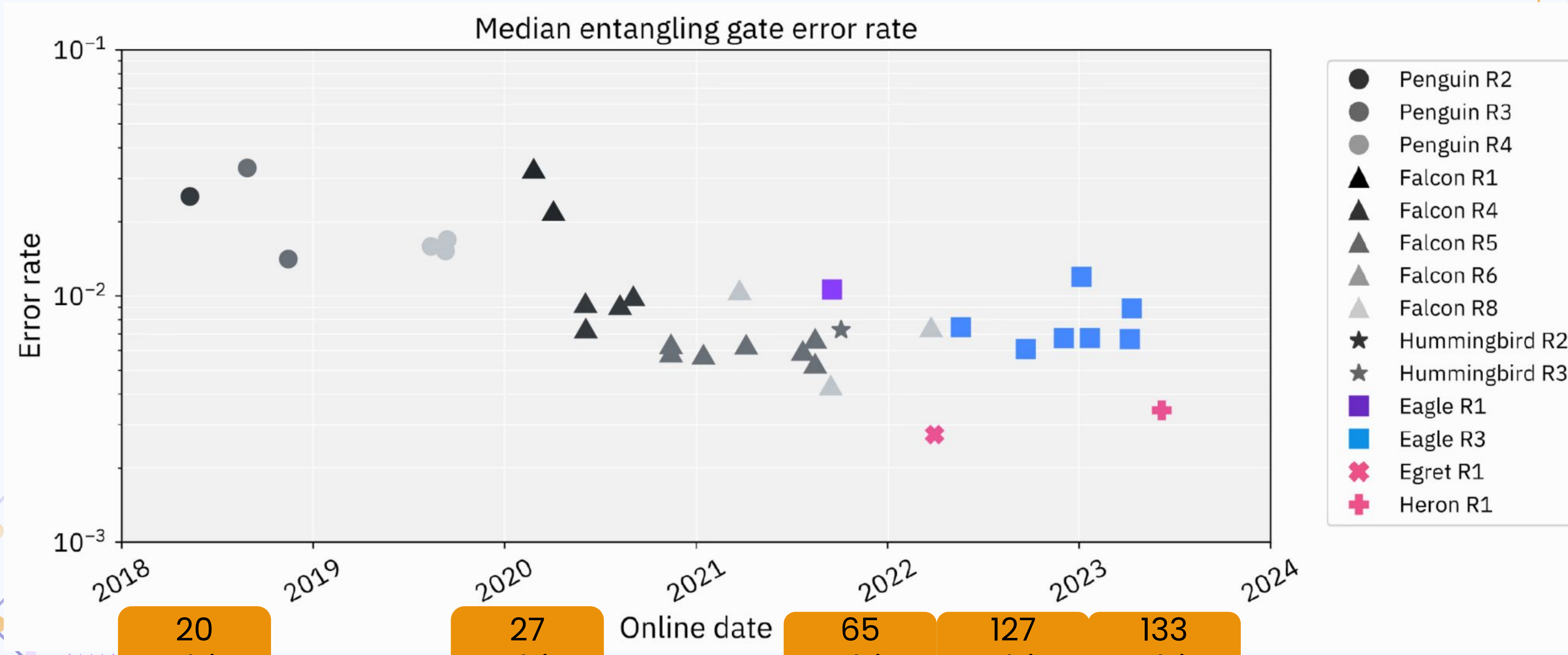

20 qubits

27 qubits

65 qubits

127 qubits

133 qubits

Quantum controllers

Y. Xu et al., "QubiC: An Open-Source FPGA-Based Control and Measurement System for Superconducting Quantum Information Processors," in IEEE Transactions on Quantum Engineering, vol. 2, pp. 1-11, 2021, Art no. 6003811, link

Quantum Machines OPX+ marketing page

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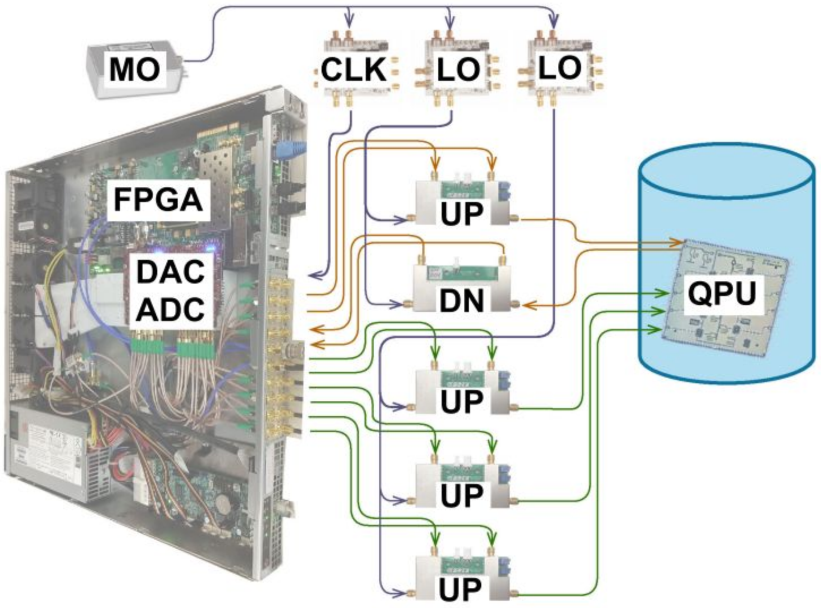

FIGURE 1. QubiC prototype hardware. MO: master oscillator, CLK: clock, LO: local oscillator, FPGA: field-programmable gate array, DAC: digital-to-analog converter, ADC: analog-to-digital converter, UP: upconverter, DN: downconverter, QPU: quantum processor unit. The yellow line indicates the measurement path, while the green line defines the qubit control path.

Other non-silicon computers

You can make a logic gate out of so many things! (sources)